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**OPTICAL PRESSURE AND
TEMPERATURE MAPPING**



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14. ABSTRACT Experimental validation of turbine performance is a challenging task because the high temperatures, scale of the hardware, and gas composition make taking data in a real turbine virtuously impossible. Facilities such as the Air Force Turbine Research Facility (TRF) enable acquisition of data through simulation of the turbine environment. This blow-down facility for testing full-scale turbine hardware allows control of the gas temperature and composition and matches the Reynolds number, pressure ratio, corrected speed, and temperature ratios in a more benign environment. The facility is instrumented with thermocouples, heat-flux gauges, and pressure taps for collecting experimental data. Typically high-frequency-response measurements are made at particular static locations, resulting in low spatial resolution. Recently these measurements have been supplemented with temperature – (TSP) and pressure-sensitive paints (PSP) that allow high-spatial-resolution measurements at low frequency. In this test program, temperature, pressure, and heat flux are measured using traditional gauges, and temperature and pressure are measured using TSP and PSP at a range of flow conditions. A comparison of the thermocouple and pressure-tap data with the TSP/PSP data indicates similar mean results, suggesting that the paints can be implemented into the TRF and high-spatial-resolution data obtained with reasonable accuracy at moderate temperatures.					
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1 INTRODUCTION

Traditional techniques for acquiring surface-temperature and -pressure data on wind-tunnel models have utilized embedded arrays of thermocouples, heat-flux gauges, and pressure taps. This approach requires significant model construction and setup time while producing data with limited spatial resolution. Furthermore, physical constraints such as mechanical movement, section thickness, and wiring access can preclude the use of thermocouples and pressure taps in certain regions of a model. Because of these limitations, it is difficult to determine accurately a loading curve or resolve the film-cooling flow distribution behind a coolant hole--among other items of potential interest to the turbine designer. An alternative approach that has received considerable attention over the past 15 years is the use of luminescent probes that are sensitive to temperature and pressure. These techniques, known as Temperature- and Pressure-Sensitive Paint¹ (TSP and PSP), have resulted in high-spatial-resolution measurements of temperature and pressure on surfaces that in the have proven past to be inaccessible. In fact, measurements of temperature and pressure have been demonstrated on first-stage compressor blades using TSP and PSP by several teams.^{2, 3, 4} This type of data is of particular value at the Turbine Research Facility (TRF) where full-scale turbine hardware is characterized, including full film cooling. Obtaining the details of the flow along the airfoil surface is of significant interest in determining shock locations, separation regions, and film distributions. Exact locations of these types of spatial-dependent cooling events are almost impossible to obtain from embedded or surface-mounted hardware. Effective implementation of PSP and TSP would provide an effective supplement to the current instrumentation at TRF as well as similar facilities.

2 PRESSURE-SENSITIVE PAINT (PSP)

A typical PSP is composed of two main parts--an oxygen-sensitive fluorescent molecule and an oxygen permeable binder. The PSP method is based on the sensitivity of certain luminescent molecules to the presence of oxygen. When a luminescent molecule absorbs a photon, it transitions to an excited singlet energy state. The molecule then typically recovers to the ground state by the emission of a photon of a longer wavelength. In some materials oxygen can interact with the molecule such that the transition to the ground state is non-radiative; this process is known as oxygen quenching. The rate at which these two processes compete is dependent on the partial pressure of oxygen present, with a higher oxygen pressure quenching the molecule to a greater extent, thus emitting light of a lower intensity. Intensity-based pressure measurements using PSP are accomplished by coating the model surface with the paint and illuminating the surface with light of the appropriate wavelength to excite the luminescent molecule. Luminescence from the surface is collected through a long-pass filter that separates the luminescent signal from the excitation light, and the luminescent signal is recorded. A schematic of the basic equipment and methodology is shown in Figure 1. Unfortunately, the luminescent signal from the paint is a function not only of pressure but also of illumination intensity, probe concentration, paint-layer thickness, and detector sensitivity. These spatial variations result in a non-uniform luminescent signal from the painted surface. The spatial variations are eliminated by taking the ratio of the luminescent intensity of the paint at an unknown test condition, I , to that at a known reference condition, I_o . Using this *wind-on* to *wind-off* ratio, the response of the system can be modeled using a modification of the Stern-Volmer equation

$$\frac{I_o}{I} = A(T) + B(T) \frac{P}{P_o} \quad (1)$$

2.1 Sources of Error for PSP Measurements

Liu⁵ has investigated and modeled sources of uncertainty for PSP measurements, including temperature, illumination, model displacement/deformation, sedimentation, photo-degradation, and shot noise. He concluded that the major sources of error are temperature and illumination. Note in Eq. (1) that the Stern-Volmer coefficients, $A(T)$ and $B(T)$, are functions of temperature. These coefficients are temperature dependent since temperature affects both non-radiative deactivation and oxygen diffusion in a polymer. In fact, the temperature dependence of $A(T)$ is due to thermal quenching, while that of $B(T)$ is related to the diffusivity of oxygen in a polymer binder.

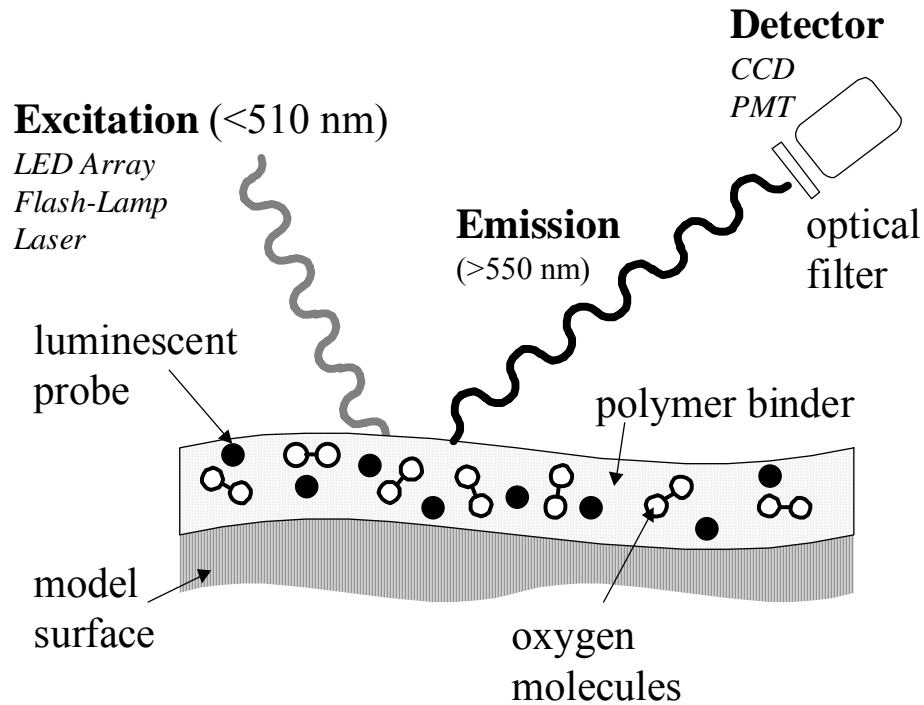


Figure 1. Basic PSP System.

Temperature sensitivity can lead to errors in converting the intensity distributions to pressure. This is demonstrated by considering a calibration of a PSP that is composed of Platinum tetra(pentafluorophenyl)porphine (PtTFPP) in Fluoro/Isopropyl/Butyl (FIB), as shown in Figure 2. The quantity I_o/I is a monotonic function of pressure along each isotherm. The *wind-on* and *wind-off* data, however, must be acquired at the same temperature if the conversion to pressure is to be free from temperature errors. A second temperature-related issue is the slope of the curve along each isotherm. For most PSPs the slope of the sensitivity curve is a function of temperature. An accurate measurement of the absolute temperature is necessary for correct conversion of the intensity ratio to pressure. An important property of the PtTFPP/FIB paint is the property of ideality.⁶ For an ideal paint, the slope of the sensitivity curve is independent of temperature--a property of significance for minimizing temperature errors in PSP measurements.

For radiometric PSP, errors in pressure measurements due to temperature are largely the result of changes in the temperature of the model surface between the acquisition of the *wind-off* and the *wind-on* data. However, any temperature gradient on the model surface results in a temperature-induced error in the pressure measurements. A temperature

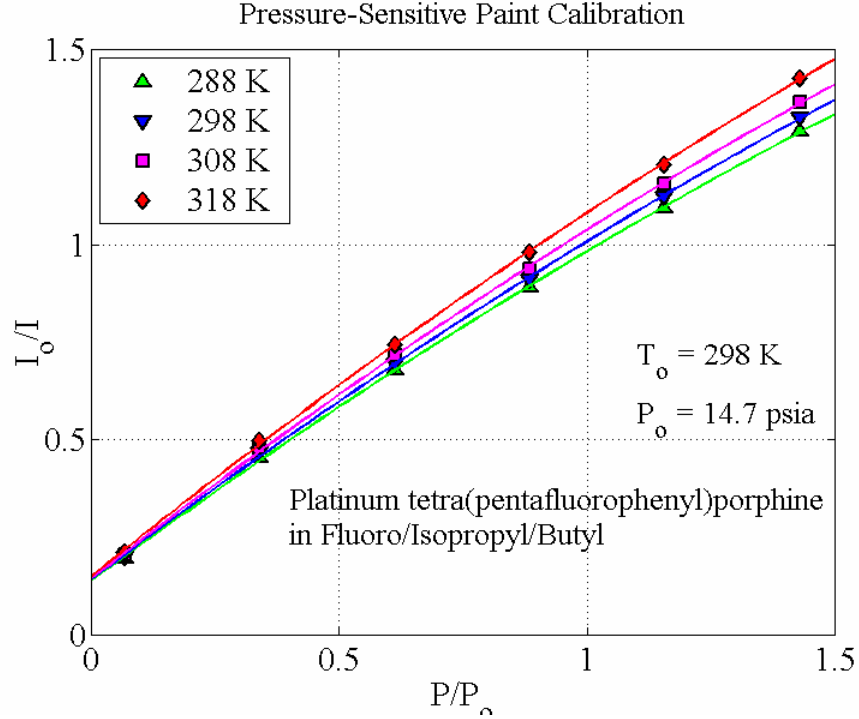


Figure 2. Calibration of PtTFPP in FIB.

difference between the vane and the free-stream fluid results in a heat flux at the surface of the vanes; thus, the temperature of the painted surface could be changing throughout the run. Since the TRF is a blow-down facility, the total temperature of the flow is dynamic throughout the run; therefore, the issue of temperature errors is difficult to avoid. In fact, this effect is most apparent during the heated runs.

The relationship between surface illumination and paint luminescence is linear; therefore, any change in surface illumination results in an equal change in paint luminescence. Errors in pressure measurements caused by variations in surface illumination can stem from several sources such as displacement or deformation of the model. The construction of the TRF is such that this type of error is of minor importance. Another source of illumination errors is the temporal stability of the illumination source. Any variation of the intensity of the illumination source between the *wind-off* and the *wind-on* images will register as an error in illumination. The illumination source utilized here is a solid-state laser. The quoted stability of the laser is better than one-tenth of a percent per hour, which is sufficiently stable for these measurements. Finally, uncertainty in PSP measurements is a function of the ratio of the *wind-off* pressure to the *wind-on* pressure. Care must be taken to ensure that the *wind-off* data are acquired at a condition near the anticipated *wind-on* conditions to minimize this uncertainty.

2.2 Binary PSP

The experimental approach envisioned for the first TRF entry was to use a vane painted with a TSP to measure and compensate for temperature errors from the PSP vane. This approach was not sufficient to compensate for the temperature changes that occurred throughout the TRF run cycle. During the first entry it became apparent that the TSP and PSP data should be acquired simultaneously from a single vane using a single paint. In future tests this goal can be accomplished by embedding into the PSP a second probe that is sensitive to temperature but not pressure. This is generally known as a binary paint, and several groups have successfully demonstrated this approach.^{7, 8, 9} One limitation to these techniques is the need to view the signal and reference probes independently; this is generally accomplished using a filter switch or two detectors. Because of physical constraints in the TRF, these approaches are not desirable; the binary paint must be implemented using a single detector and data acquired from the two channels simultaneously. A new technique that offers a potential solution is the temporally resolved^{10 11} or dual-lifetime¹² approach.

2.3 Dual-Lifetime PSP

The basis of the dual-lifetime approach is shown in Figure 3. A PSP is created with two luminescent dyes--one being a standard pressure sensor with a longer lifetime ($\sim 10\text{-}100\ \mu\text{s}$) and the other being a temperature sensor with a shorter lifetime ($< 1\ \mu\text{s}$). When the paint is excited by an LED, the response of the system is a superposition of the response of the individual dyes. The response of the *fast* dye tracks the lamp pulse since this dye has a lifetime that is shorter than the rise and fall time of the lamp, while the *slow* dye exhibits the standard exponential rise and decay in luminescence. The signal from each dye is discriminated in time by integrating the signal near the beginning and end of each excitation pulse from the lamp. A short gate near the leading edge of the lamp pulse is dominated by the shorter lifetime dye, while a longer gate placed just after the trailing edge of the lamp pulse isolates the longer lifetime dye. The width and position of these gates is selected in such a way that the ratio of the gates is a function of pressure only, i.e., the temperature sensitivity of the two gates is identical, but the pressure sensitivity is different. An example of calibration of the dual-lifetime paint, which exhibits minimal temperature sensitivity, is shown in Figure 4.

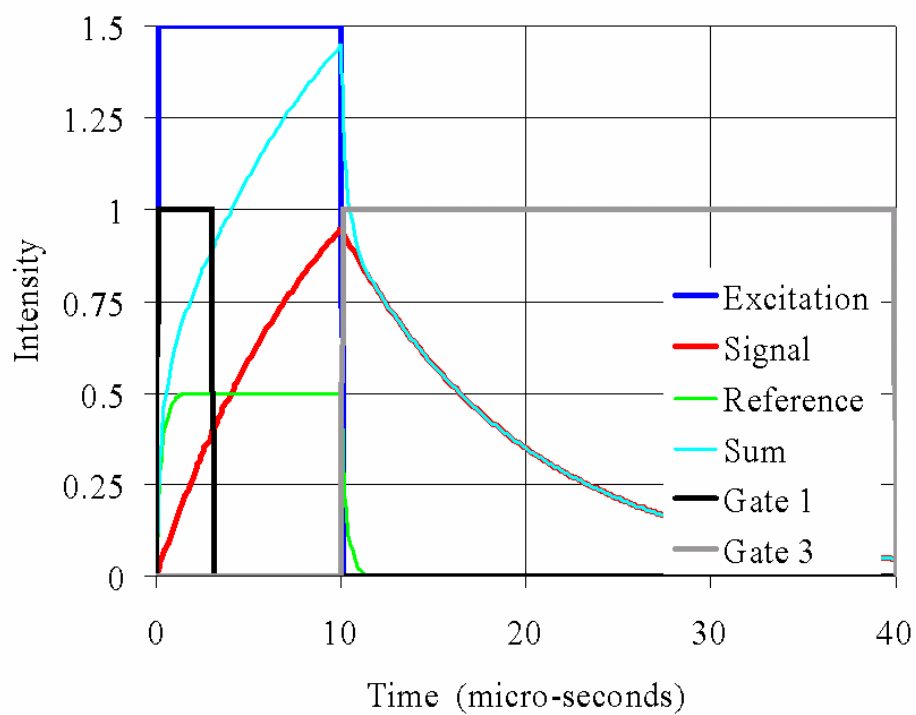


Figure 3. Dual-Lifetime-PSP Approach.

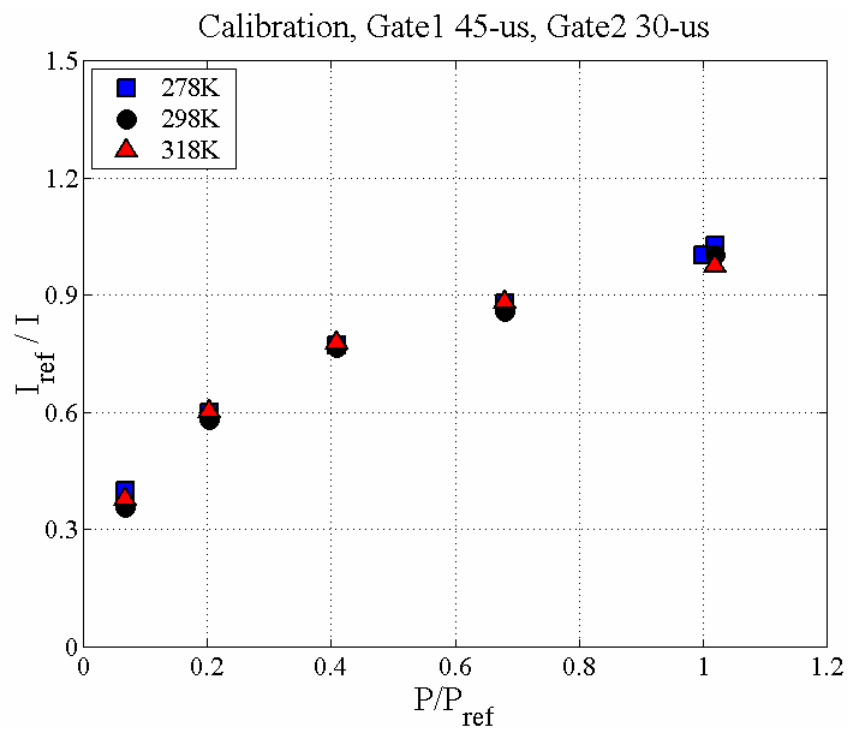


Figure 4. Dual-Lifetime-PSP Calibration.

3 EXPERIMENTAL FACILITY

The TRF, shown in Figure 5, is a blow-down facility for testing full-scale turbine hardware. The system is composed of a supply tank and a pair of vacuum tanks, with the turbine hardware residing between the supply and vacuum tanks. Both upstream and downstream of the test article is a traversing ring, which provides a means of rotating probes, such as total pressure rakes, relative to the turbine hardware during a blow down. To perform a test, the supply tank is filled with gas (usually nitrogen), pressurized, and heated to an aerothermodynamic match point—one that matches the Reynolds number and temperature ratio for the turbine. An isolation valve acts as a choke for the system and controls the pressure ratio. Facility startup is accomplished by opening the main valve, which initiates the blow-down process as well as the data-acquisition and traversing systems. Flow proceeds through the test article and past the isolation valve into the initially evacuated dump tanks. The total run time is about 5 s, and this procedure can be repeated one to five times a day, depending on the run conditions.

The TRF is instrumented with pressure taps, pressure rakes, thermocouples, and heat-flux gauges, which are installed at fixed axial and radial locations on the vanes and the rotor and yield the high-frequency response needed for many purposes such as vane/rotor interactions and turbulence-structure resolution. Supplementing this capability with the ability to make measurements of pressure and temperature at any location on the vanes and rotor blades would be of significant value (even at lower frequency response).

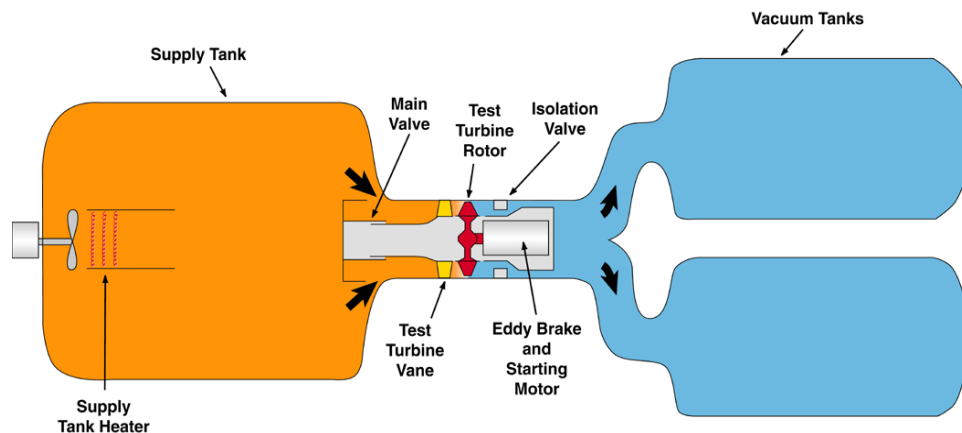


Figure 5. Block Diagram of TRF.

Optical techniques known as TSP/PSP, for making measurements of temperature and pressure based on luminescent probes, have been demonstrated on turbomachinery¹³ and can provide this needed information.

In the present study the aft section of the suction surface of an uncooled high-pressure turbine vane was investigated. This vane has multiple pieces of static instrumentation but, in particular, three flush-mounted Kulite pressure transducers in the region of interest that are mounted at nominally 50% span. These transducers are located at 0.25, 0.65, and 0.90 x/x_{ac} (where x is the axial distance and x_{ac} is the axial chord). Also, thin-film heat-flux gauges were applied to another vane at 50% span. These gauges are located at 0.25, 0.40, 0.65, 0.80, and 0.90 x/x_{ac} and served as the reference measurements with which to compare the TSP and PSP results in this investigation.

3.1 Experimental Setup

Three separate paints were applied to three individual vanes in the TRF in one quadrant of the facility. Two vanes were coated with PSP (UniCoat and UniFIB), and one vane was coated with TSP (UniT-01). UniCoat is a latex-based paint that can be easily dispensed from an aerosol can, which simplifies the application process. UniFIB is a high-performance paint that offers low temperature sensitivity and high pressure sensitivity. UniFIB must be sprayed using an airbrush and cured using heat treatment; this results in a more labor-intensive application process. UniT-01 is a TSP, which--like UniCoat--is dispensed from an aerosol can. The role of the TSP in this test is to monitor temperature changes that occur between the pre-run scan and the run as well as detect temperature gradients on the vane surface during the run. These paints were chosen for this first investigation because they are compatible with the chosen 532-nm excitation source, thus simplifying the data-acquisition system. The vanes were cleaned with alcohol to remove any oil and then painted prior to closing the facility. Since the TRF is an enclosed facility, no photo-degradation of the paint was expected over time since the paint was exposed to light only during the test runs.

In the TRF no direct optical access to the vane hardware was available. To deliver the needed excitation to the PSP/TSP paint, a fiber-optic system was developed that utilized the existing downstream traversing ring. The data-acquisition system, shown in Figure 6, is a scanned point system. A 532-nm laser was used as the excitation source for this experiment. The laser was coupled into a fiber optic, which was fed through the bulkhead of the TRF using an SMA-to-SMA connector. A second fiber optic was used to carry the

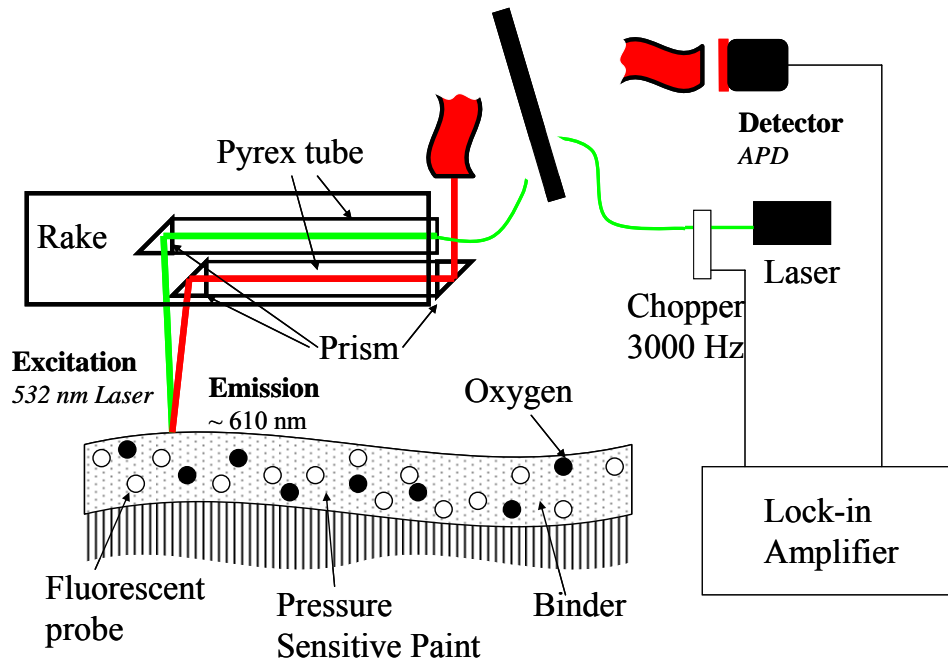


Figure 6. Data-Acquisition System.

beam to a set of collimating optics that was coupled to a Pyrex tube. The tube was embedded in a modified downstream rake. A prism on the end of the tube turned the light onto the vane, providing a spot on the painted surface. Luminescence from the vane was collected through a second port in the rake. The tube was equipped with a pair of prisms for steering the fluorescence into a liquid light guide that carried the fluorescence back to the bulkhead where a compression fitting was used to feed the end of the light guide through the bulkhead. The fluorescence was passed through a 610-nm long-pass filter and collected by an avalanche photo-diode (APD). The photo-diode signal was detected and demodulated by a lock-in amplifier (LIA). Finally, scanning the point across the surface of the vanes was accomplished by rotating the ring-mechanism rake past several vanes during the run.

The composition of the gas in the supply tank for the TRF facility can be controlled by the user. With this feature the partial pressure of oxygen at each test condition was set to an optimized level. Most of these runs were performed at an initial supply-tank pressure between 30 and 75 psia. The signal-to-noise ratio (SNR) of this PSP system was optimum when the partial pressure of oxygen was near 1 psia; therefore, the composition of the supply tank was set between two and six percent oxygen for this series of tests. This was accomplished by filling the tank with nitrogen and adding air until the desired O₂ concentration was achieved.

Paint results were reduced by ratioing the data obtained during a run against a similar traverse performed at a steady pressure and known O₂ concentration. This creates the *wind-on* and *wind-off* conditions described previously. These two traverses were aligned utilizing the sharp change in signal that occurred as the scan passed the vane trailing edges and two markers at known locations on one vane. Once this ratio was obtained, short time windows of 10-ms length were created, and the average intensity ratio was converted to pressure using the appropriate paint calibration. This is, in essence, a spatial average of the pressure over the portion of the vane that was traversed during the 10-ms window. The spatial resolution thus was about 1% chord for this investigation, which corresponded to 50 measurements over the last 60% of the vane suction surface.

One issue of concern for this test was the stability of both TSPs and PSPs during the experimental campaign. Contaminants in the TRF can damage the luminescent probes or poison the binders in which they reside. The issue of paint stability was investigated by performing a series of in-situ calibrations of the paints over the course of the two-week campaign. The static pressure inside the test section of the TRF can be controlled; therefore, the pressure was set at several different levels, and a *wind-off* scan of the vane was performed. This in-situ calibration was repeated three times during the two-week test program. A plot of both intensity ratio and lifetime as a function of pressure for UniFib, shown in Figure 7, indicates that the calibration of UniFib does not change significantly over the course of the tests. Similar stability in the calibration of the other two paints was observed. It was concluded, therefore, that the TRF environment does not contain contaminants that damage the performance of the paints.

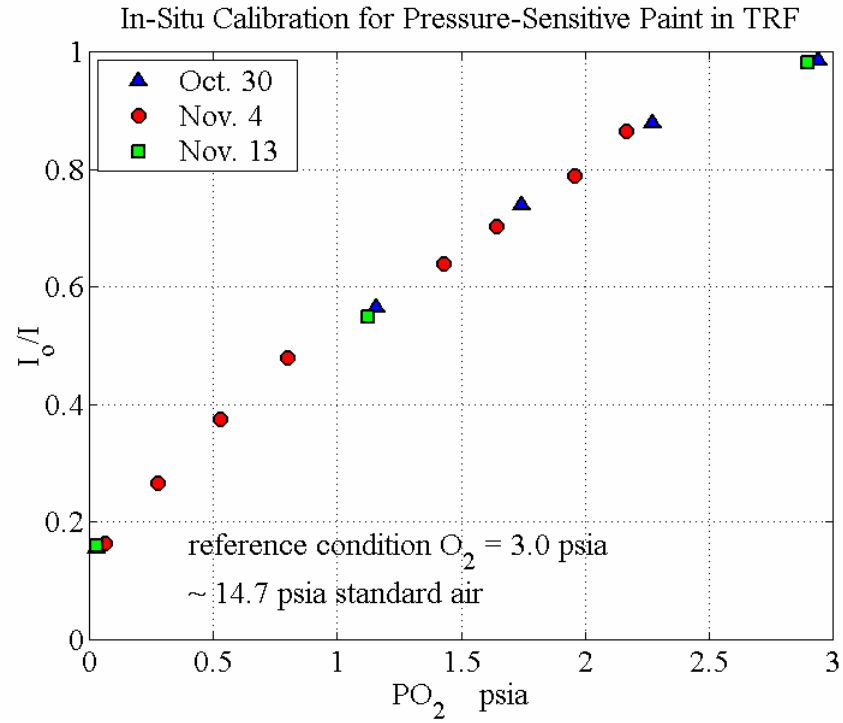


Figure 7. In-Situ Calibration, Demonstrating PSP Stability During Two-Week Test Campaign.

4 FIRST-ENTRY RESULTS

The first concern was to verify that the PSP-system performance was repeatable and independent of oxygen concentration. The first two experiments were performed with tank pressure near 40 psia, tank temperature at 316 K, and oxygen concentrations of 3.2 and 6.2%. The results for these two runs have been normalized by the upstream pressure, and these results are shown in Figure 8. First, note that the PSP results are in good agreement with those from the pressure taps near this span on the vane. A slight difference was noted in the supply-tank pressure for these two cases; this is manifested in the small shift that is evident in both the PSP and the Kulite data. However, normalization of the data by the supply-tank pressure results in agreement of the data for these two tests to within the uncertainty of these measurements and, thus, confirms that the data-acquisition system is not dependant on oxygen concentration. The uncertainty is a function of the partial pressure of oxygen since this is the component to which the system is sensitive. It is estimated that the uncertainty is ~ 0.05 psi of O_2 . The repeatability of the PSP measurements was confirmed by performing a third test using tank pressure near 40 psia, tank temperature of 316 K, and an oxygen concentration of 6.2%. The data were again in good agreement with those of the preceding run; thus, the repeatability of the PSP system was demonstrated.

The pressure distributions on the suction surface of the vane are shown in Figure 9 for three Reynolds numbers--136,000, 265,000, and 550,000 runs. As the Reynolds number was increased, the pressure on the suction surface decreased, serving to increase the loading, as expected. Again the PSP results matched well with the static-pressure-tap data for these three runs. More importantly, the PSP resulted in over 50 data points, as compared to three from the static taps. This provides more accurate resolution of the loading on this vane than can be provided by the surface transducers. Some of the variations plotted with span are real and of importance to the turbine designer. Some, however, are artifacts of the noise level in the PSP measurements being higher than expected, which is primarily the result of a low SNR for the system as configured here. The SNR can be improved by using a stronger excitation source and improving the design of the optical system in the rake. These modifications have been implemented; this will be described later.

Of substantial interest is the ability to perform tests with heated air in the TRF. Several tests were performed in this mode to evaluate the PSP measurements for heated runs.

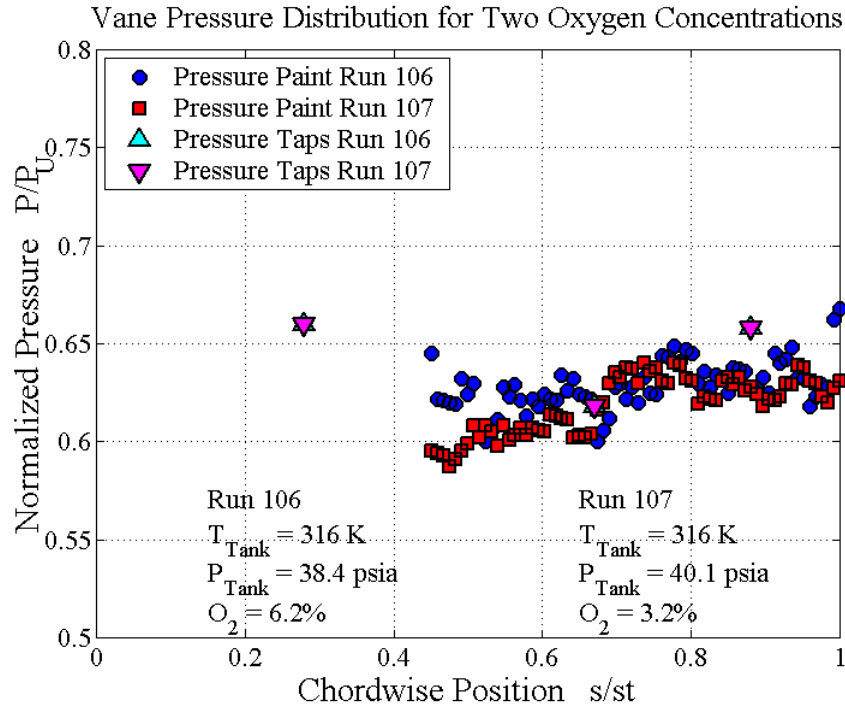


Figure 8. Normalized Pressure Near 50% Span for Two O_2 Concentrations.

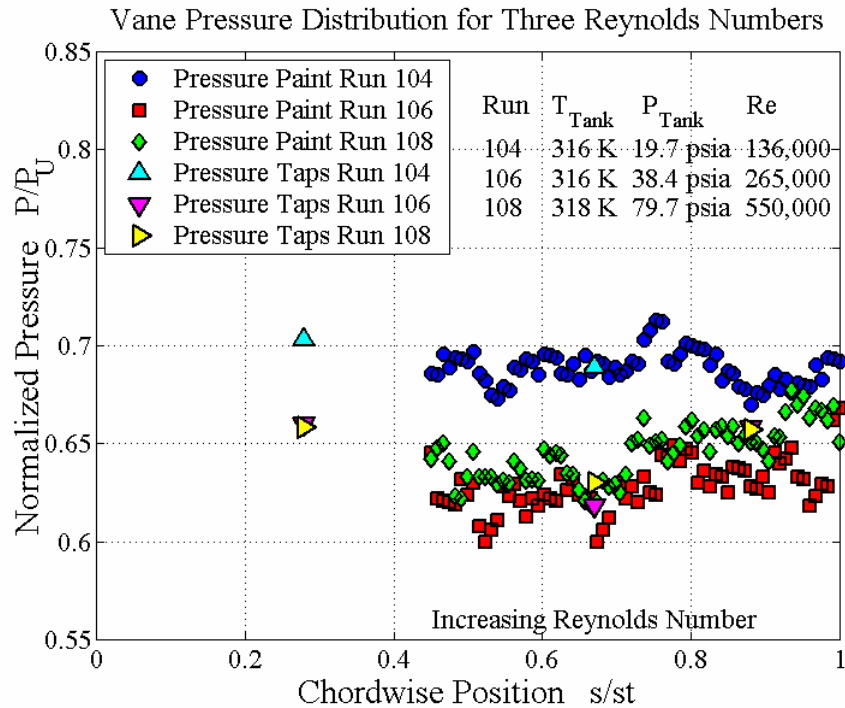


Figure 9. Pressure Data Obtained at 50% Span for Three Reynolds Numbers.

The tank pressure was set at 47 psia, and the tank was heated to 368 K. The PSP and TSP results are presented in Figure 10. First note the significant deviation in the paint and the Kulite results--particularly at the aft portion of the vane. Also note the presence of a chord-wise temperature gradient on the vane. This temperature profile is evident in both the thermocouple and the TSP data. The TSP data, however, are noisy; nevertheless, it is evident that the temperature of the aft portion of the blade is lower than that of the central portion. It also appears that a strong temperature gradient is present in this aft portion of the vane. The temperature sensitivity of PSP has been discussed previously. It should be noted here that the lower temperatures on the aft portion of the vane should result in a rise in pressure for the PSP; this trend is displayed in Figure 10.. One might question the absence of this temperature issue in the PSP data for the unheated runs. Some insight can be gained by comparing the TSP and thermocouple data for a heated and an unheated run shown in Figure 11. For the unheated runs the temperature of the vane is relatively constant over the entire chord; the PSP data, therefore, suffer little or no temperature error. The deviation in pressure on the aft portion of the vane in Figure 10 is attributed to the temperature distribution on the vane that resulted from the heated-run condition.

One might be tempted to use the TSP or thermocouple data to correct the PSP data for temperature effects. Unfortunately, this is not effective for several reasons. The TSP and PSP measurements were made on separate vanes, at separate times, and for different polymer binders. The issue of concern is the thermal history of the system. The temperature of the paint on the vane is a function of the heat flux to the vane and time. At a given location one must consider the heat-transfer coefficient, the paint-layer thickness and thermal conductivity, the thermal mass of the system, and the free-stream temperature. Since this is a blow-down facility, the free-stream temperature is decreasing throughout the run. The TSP and PSP utilize different polymer materials, have different thicknesses, and, therefore, present different boundary conditions for heat transfer. Finally, it should be noted that the thin trailing edge of the vane appears to suffer the most significant temperature rise, which could be due to the smaller thermal mass of this portion of the vane. The higher heat flux presented by the heated runs will saturate this portion of the blade more rapidly and, thus, result in a higher temperature. Unfortunately, the temperature at any point on any painted surface will be a function of both time and the properties of the paint and vane at that point. It is necessary to measure both the temperature and the pressure at each point simultaneously. For this reason we have developed a temporally resolved binary paint to improve the system accuracy. The binary

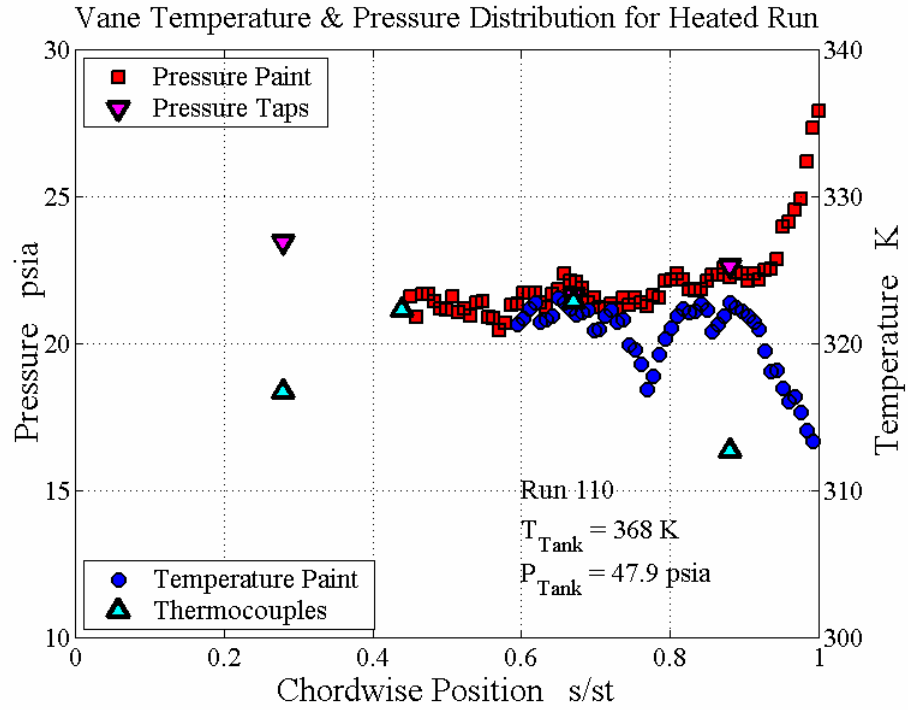


Figure 10. Pressure Data Obtained at 50% Span at Elevated Temperature.

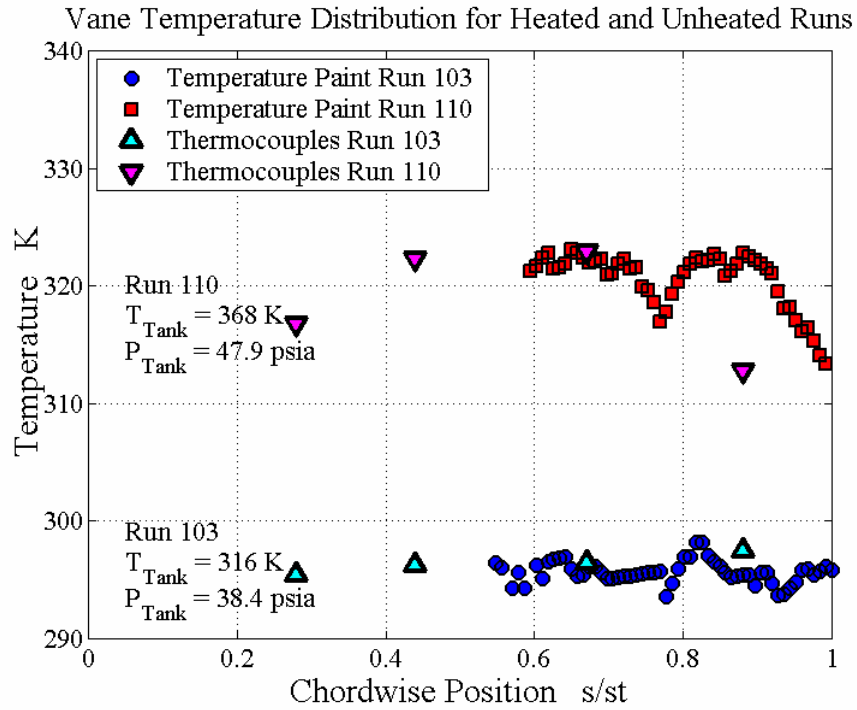


Figure 11. Temperature Data Obtained at 50% Span for Heated and Unheated Runs.

paint will allow both PSP and TSP measurements on the same vane at the same time, enabling compensation for errors caused by temperature variation on the stator.

4.1 Summary

Results from the first entry into the TRF indicate that the calibration of the PSP was stable throughout the two-week test, which indicates that the TRF environment does not contaminate the paint. The complex optical system designed for the initial test resulted in a significant loss of signal strength and, thus, a low SNR for the initial measurements. Heated runs introduced a second source of error--a non-uniform temperature distribution on the vane. These noise sources resulted in the data having a higher level of uncertainty than anticipated. In spite of these issues, the PSP results are consistent with the data from the in-situ pressure taps, and PSP provides the high spatial resolution needed to supplement the high-frequency-response taps. Improvements to the system that should reduce the noise level in the measurements include an improved optical design and a binary paint to compensate for temperature errors. These improvements were developed as part of this program and are discussed in the following sections.

5 IMPROVED DESIGN FOR OPTICAL PROBE

In the initial experiments it was determined that the SNR was not sufficient to produce data having the desired accuracy. Furthermore, the dual-lifetime paint that is to be used for temperature correction requires that the intensity of the paint signal be recorded directly to allow time-resolved processing. Improving the optical-probe assembly was identified as a key task for future tests.

The fiber-probe system utilized in the first TRF entry is shown in Figure 6. The excitation is coupled into a fiber optic, which is fed through the bulkhead of the TRF using an SMA-to-SMA connector. Inside the bulkhead, a second fiber optic is used to carry the excitation to a set of collimating optics coupled to a Pyrex tube, which is embedded in a downstream pressure rake. A prism on the end of the tube turns the light onto the vane, providing a spot on the painted surface. Luminescence from the vane is collected through a second port in the rake. The Pyrex tube is equipped with a pair of prisms for steering the fluorescence into a liquid light guide, which carries the fluorescence back to the bulkhead where a compression fitting is used to feed the end of the light guide through the bulkhead. The fluorescence is passed through a 610-nm long-pass filter and collected by an APD. The photo-diode signal is detected and demodulated by a LIA. Finally, scanning the point across the surface of the vanes is accomplished as the ring mechanism rotates the rake past several vanes.

5.1 PLIS Fiber and Collimating Optics

The first component of the probe to be replaced was the internal fiber and collimating optics. The coupling of the external and internal fiber through the SMA-to-SMA connector was very inefficient, and the large bend radius of the 600- μm fiber obstructed the traversing-ring channel. Of equal importance was the ineffective collimation optics. A small fiber collimator was attached to the end of the internal fiber to create a small spot at the interrogation region of the vane. The use of the fiber collimator was effective over short distances; unfortunately, after leaving the collimator the light had to move through a 4-in. Pyrex rod and a small prism before exiting toward the vane surface which was still about 2 in. away. The quality and diameter of the resulting spot were not sufficient.

A solution to several of these problems is the use of a new wafer-inspection technology known as the PLIS fiber (Figure 12). This fiber is constructed of $\sim 0.5\text{-mm}$ -diameter acrylic with an external housing. One end of the fiber is un-terminated, while

the other incorporates collimating optics. The beam divergence from this fiber is less than 2 deg. The large-diameter fiber should produce a more efficient coupling through the SMA-to-SMA bulkhead connector. The integrated collimating optics located inside the rake probe--and, therefore, near the vane surface--should yield a small spot for setting the probe volume for the system. Several of these fibers were purchased, and the rake probe was modified to integrate the PLIS fiber. A preliminary test with the 532-nm laser indicated a substantial improvement in both optical coupling and spot size. A final issue of interest is the use of an LED for an excitation source. The dual-lifetime paint was developed using a pulsed-LED illumination source; therefore, it is desirable to integrate this into the TRF system. Unfortunately, preliminary tests with the PLIS fiber indicate that coupling a high-power LED into the fiber results in a substantial loss in excitation light as compared to that with the 532-nm laser. For this reason, the laser/chopper combination was retained as the excitation source.

PLIS

Type: special application

Construction: low beam divergence, long range
opposed (integrated lens), polyethylene jacket

Optical fiber diameter (mm): 0.50

Optical fiber diameter (in): .020

Core material: PMMA (acrylic)

MAX temp: 70° C (158° F)

Control End: Unterminated

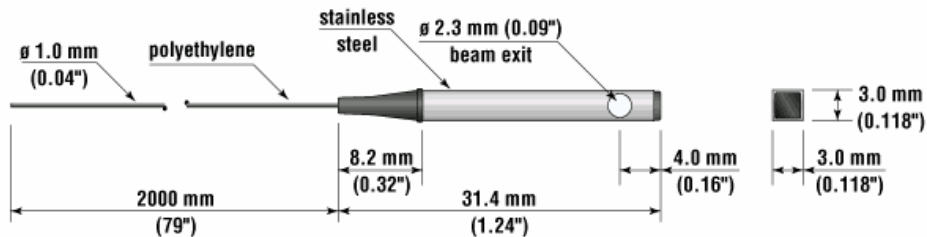


Figure 12. PLIS Fiber.

5.2 Photo-Multiplier Tube (PMT) and Data-Acquisition Board

In the initial entry an APD was used as the detector for the system. An APD is a fast, high-gain detector with good quantum efficiency in the red and near-IR spectral region. In testing the performance of the APD after the initial entry, it was found that the response of the APD to increases and decreases of the signal level was not balanced. The

APD-signal rise time was significantly faster than the fall time. Since this issue could not be resolved, the APD was replaced with a traditional PMT as the detector for the second entry.

In the initial entry a LIA and phase-sensitive-detection scheme was used for signal acquisition. The LIA provides excellent noise rejection and the ability to resolve the lifetime of a single probe. In the redesigned system a dual-lifetime paint will be used; therefore, the rise and fall of each probe on each excitation cycle must be recorded, as shown in Figure 13. To accomplish this, the data-acquisition system will employ a 12-bit, 1.25-MHz A/D board. Both the excitation and paint response will be recorded at 2- μ s intervals. The improved system, incorporating the PLIS fiber optic, PMT, and fast A/D board, is shown in Figure 14.

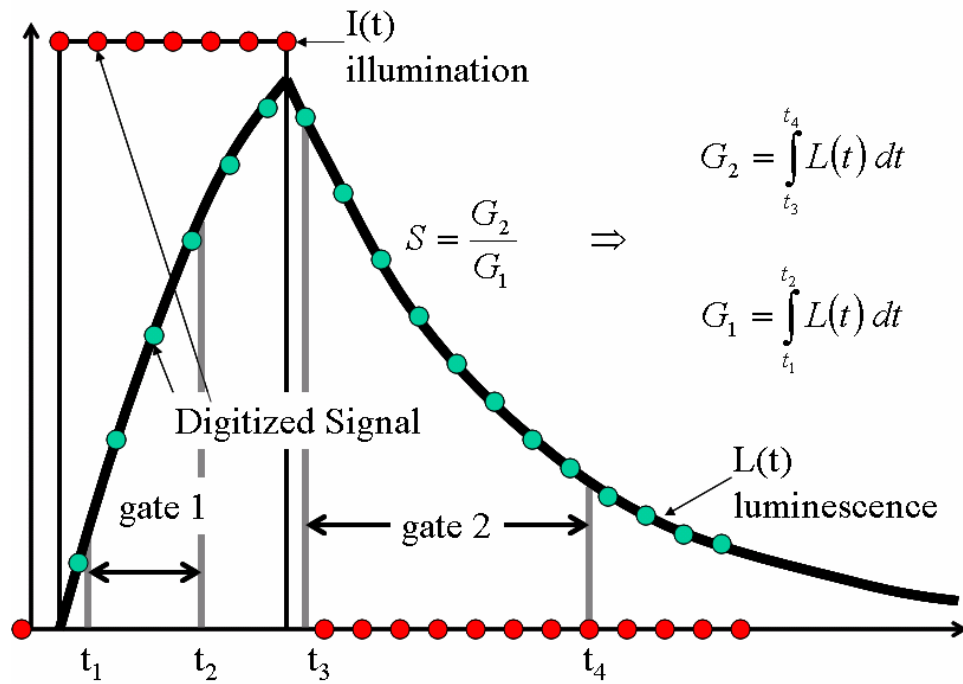


Figure 13. Data Acquisition with Dual-Lifetime PSP.

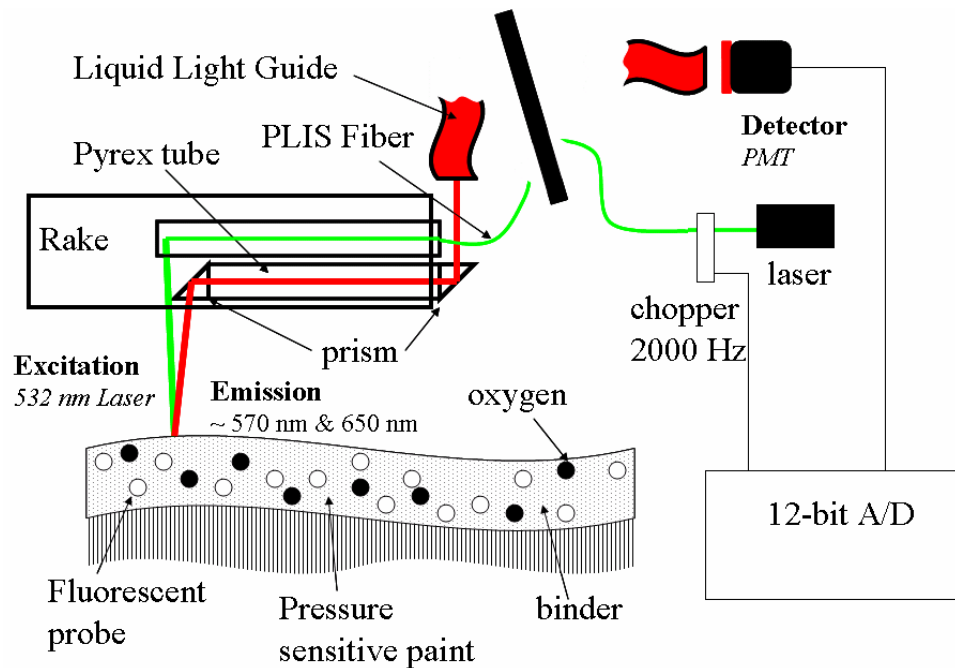


Figure 14. TRF Fiber-Probe System for Second Entry.

5.3 Test-Stand Data

To verify the operation of the system, a small set of data was acquired. The setup was identical to that of Figure 14 and included the PLIS fiber integrated into the rake probe. A small coupon with a dual-lifetime PSP was positioned about 2 in. from the probe, and the chopper was operated at 1 kHz. The data were recoded and are plotted in Figure 15. This signal represents a significant improvement over that of the initial entry, where a phase-locked loop was required to distinguish the signal from the noise.

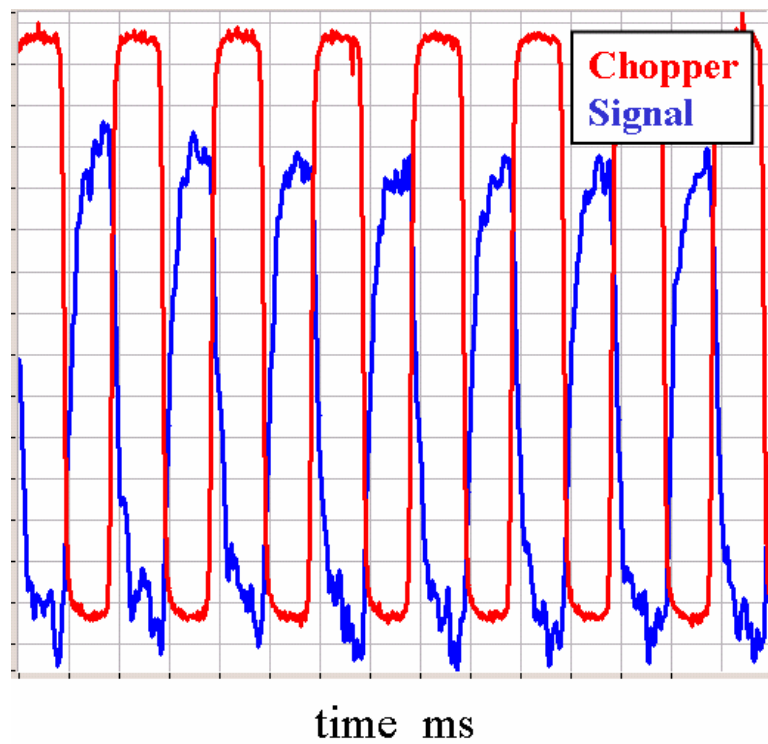


Figure 15. Sample Data Using TRF Fiber-Probe System for Second Entry.

6 CONCLUSIONS

Measurements of pressure using PSP have been conducted in the TRF. Optical access to the vanes has been gained using a fiber-optic and liquid-light-guide assembly that is integrated into an upstream rake on the traversing ring. Preliminary results indicate that the TRF environment does not contaminate the paint. The complex optical system resulted in a significant loss of signal strength and, thus, a low SNR for the initial measurements. Heated runs introduced a second source of error--a non-uniform temperature distribution on the vane. These noise sources resulted in data with a higher than anticipated level of uncertainty. In spite of these issues, the PSP results are consistent with those of the in-situ pressure taps and provide the high spatial resolution needed to supplement the high-frequency response taps. Improvements to the system that should reduce the noise level in future measurements include an improved optical probe for delivery of the excitation and a dual-lifetime paint that has minimal sensitivity to temperature. The improved system should enhance the accuracy of the PSP measurements for future tests.

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